Demand side management: a case for disruptive behaviour

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Presentation overview

1) Motivation for research
2) Contributions
3) Model description
4) Results & discussion
5) Conclusions and further research

1. Changing electricity system in the UK

The UK electricity system is changing:

Supply side	Demand-side
• Dispatchable generators replaced by renewables • System storage • Distributed electricity generation	• Small scale renewables • Consumer storage (electric, thermal) • New technology (electric vehicles, heat pumps) • Smart consumption devices

Unpredictable supply + Unpredictable demand = Difficult to balance the grid

1. Demand Side Management

Solution?

Demand side management (DSM)

Coordinate consumers to use electricity when renewable energy is abundant

Where are the gaps?

DSM has been considered in idealistic settings, i.e. identical consumers, isolated system, no market.

In reality utility companies **compete** in the wholesale market

2. Our contributions

=>Consider DSM in the context of an interacting wholesale market

Out hypothesis

Competitive behaviour by electric utilities achieved by means of shifting consumer demand can lead to increased demand peaks in the system.

Why?

'Herding behaviour'

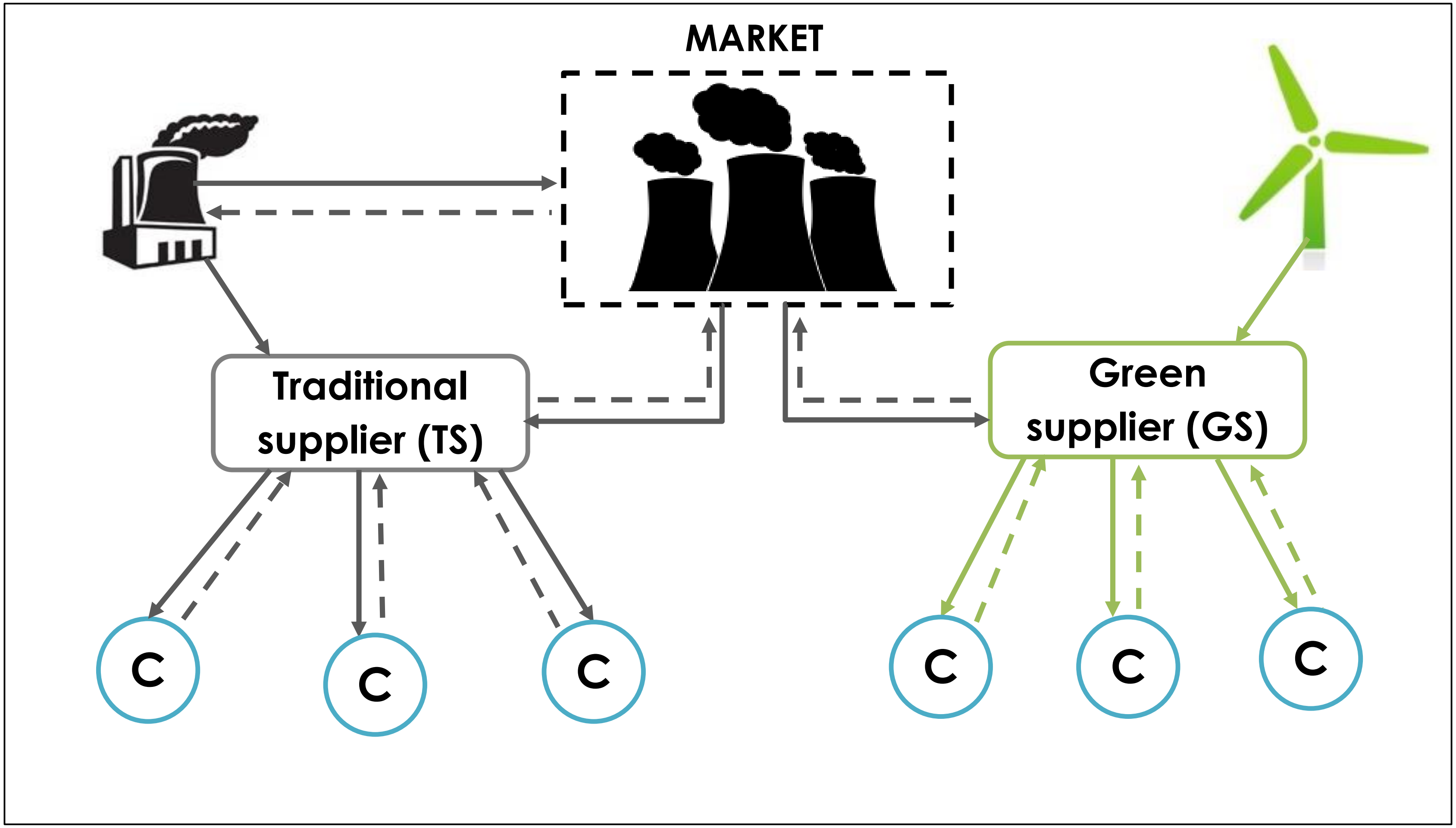
i.e. utilities make a similar prediction of future electricity prices and instruct consumer to shift demand to the same periods

=> creation of new peaks and higher electricity prices

3. Research questions

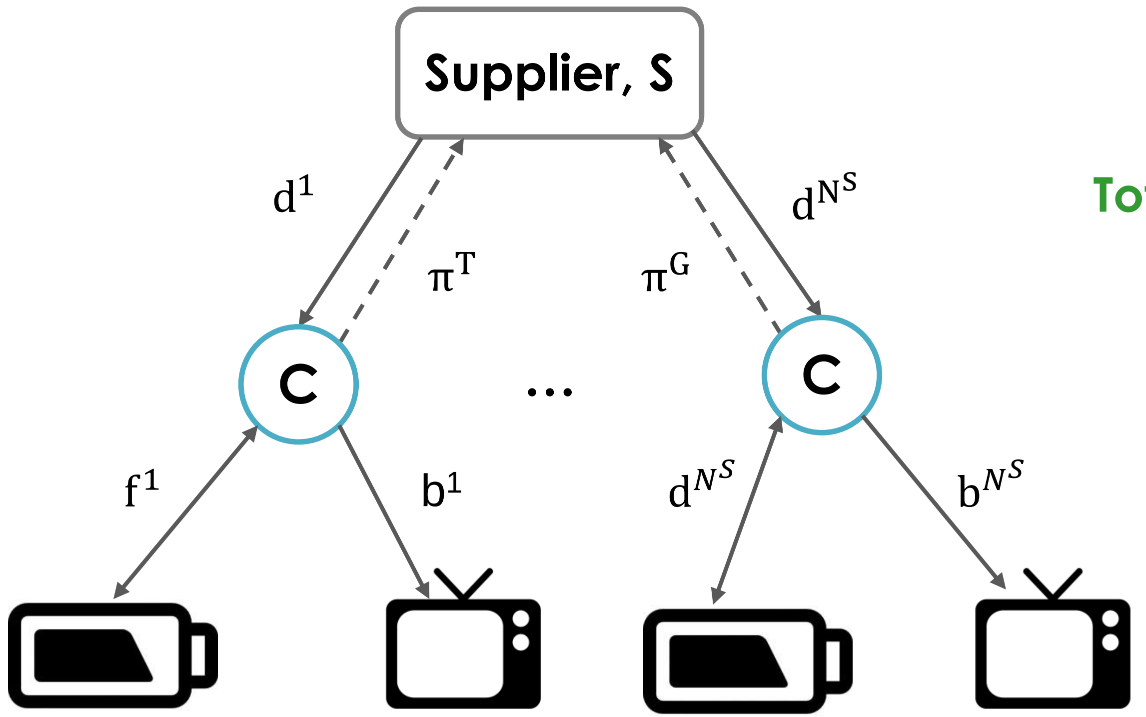
1. How could DSM influence future **business models** of electricity utilities?
2. Are there conditions under which DSM can be **disruptive** to the grid?

3. General framework



Key: C=consumer → Electricity flow - - - - → Cash flow

3. Consumers and suppliers



Total consumer demand

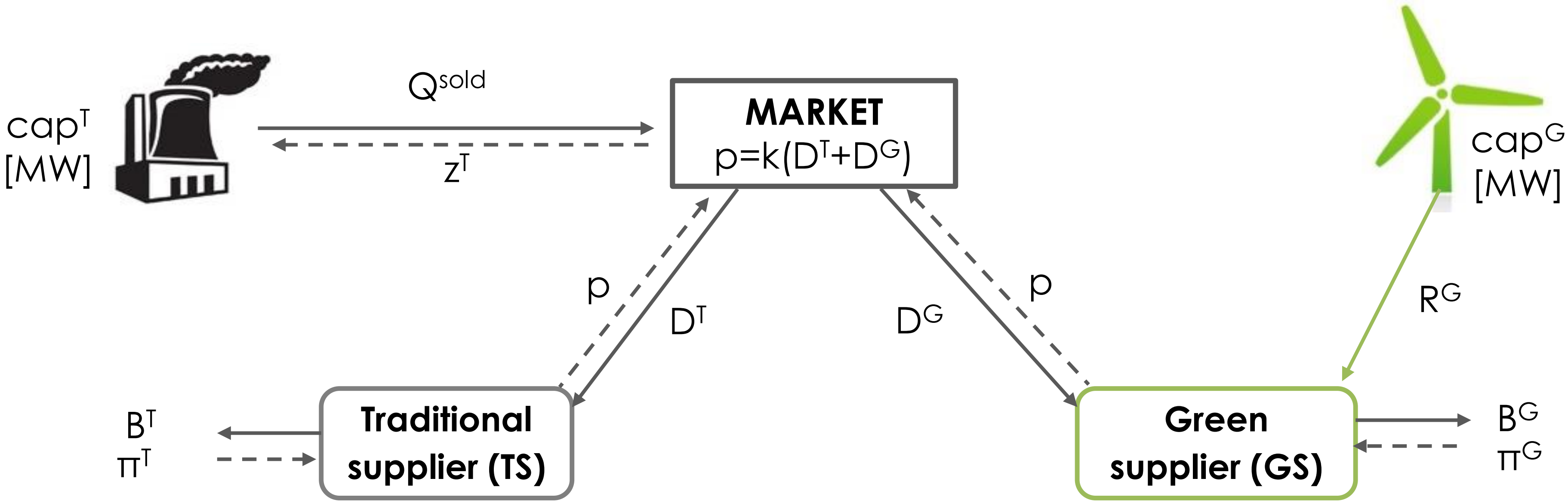
$$B^S = \sum_{a=1}^{N^S} d^a$$

Electricity flow [MWh]

Cash flow [£]

N^S	Number of consumers contracted to supplier S
a	Consumer index
b	Consumer baseload demand [MWh]
f	Consumer flexible demand [MWh]
d	Consumer net demand [MWh]
π	Retail price [£/MWh]
B	Supplier baseload demand [MWh]

3. Market



TS bidding in the market:

$$Q^{sold} = \begin{cases} Q^{gen} \leq cap^T, & \text{if } z^T \leq p \\ 0, & \text{otherwise} \end{cases}$$

Electricity flow [£/MWh]

Cash flow [£]

cap	Generator capacity [MW]	Q^{sold}	Energy sold in the market [MWh]
D,B	Net and baseload supplier demand [MW]	Q^{gen}	Energy generated by TS [MWh]
		p,π	Wholesale and retail prices [£/MWh]
R^G	Energy generated by GS [MWh]	z^T	Price offered in the market by TS [£/MWh]

3. Supplier accounting

Retail price is calculated at breakeven cost

$$\text{Retail price, } \pi^S \text{ [£/MWh]} = \frac{\text{Cost of running generator [£]} - \text{Profit from selling in the market [£]} + \text{Cost of buying from the market [£]}}{\text{Total demand supplied to consumers [MWh]}}$$

Supplier with the lowest π^S wins

3. TS learning

Assume: TS objective is to minimise the retail price π^T

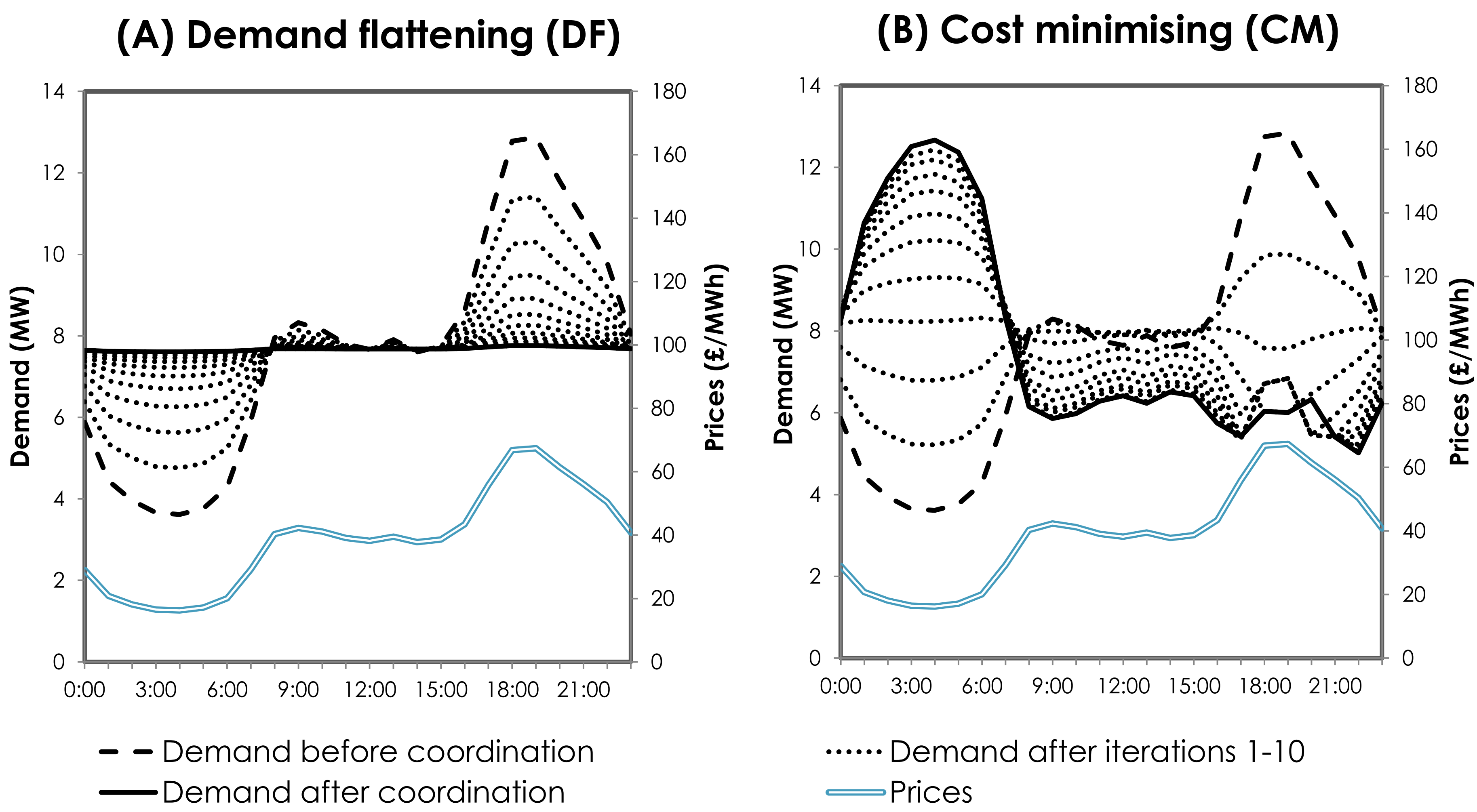
TS stores the daily outcomes in a matrix:

$$\begin{array}{ccc} \text{profit} & \text{Generated power} & \text{offer} \\ \pi(1) & Q^{gen}(1) & z(1) \\ \vdots & \vdots & \vdots \\ \pi(10) & Q^{gen}(10) & z(10) \end{array}$$

50% of the time explore new strategies for $Q^{gen}(t)$ and $z(t)$

50% of the time select $Q^{gen}(t)$ and $z(t)$ that leads to **min π^T**

3. Supplier DSM regimes



Note: algorithms adapted from Gan, L., Topcu, U., Low, S. H.: Optimal decentralized protocol for electric vehicle charging. IEEE Transactions on Power Systems, 28(2), 940951. (2013) http://doi.org/10.1109/TPWRS.2012.2210288

3. Scenarios

Parameters

- 30,000 consumers (represented by 30 agents)
- 1 Traditional Supplier (TS), 1Green Supplier (GS)
- Cost of power generation:14 £/MWh(TS), 1.5 £/MWh (GS)

Table 1: Matrix representation of the simulation scenarios.

Base case – no coordination

TS coordination	GS coordination	notation
none	none	(NC, nc)
DF	DF	(DF, df)
DF	none	(DF, nc)
none	DF	(NC, df)
CM	CM	(CM, cm)
CM	none	(CM, nc)
none	CM	(NC, cm)

Observations:

1. Retail prices: π^T, π^G
2. System demand, $D^T + D^G$

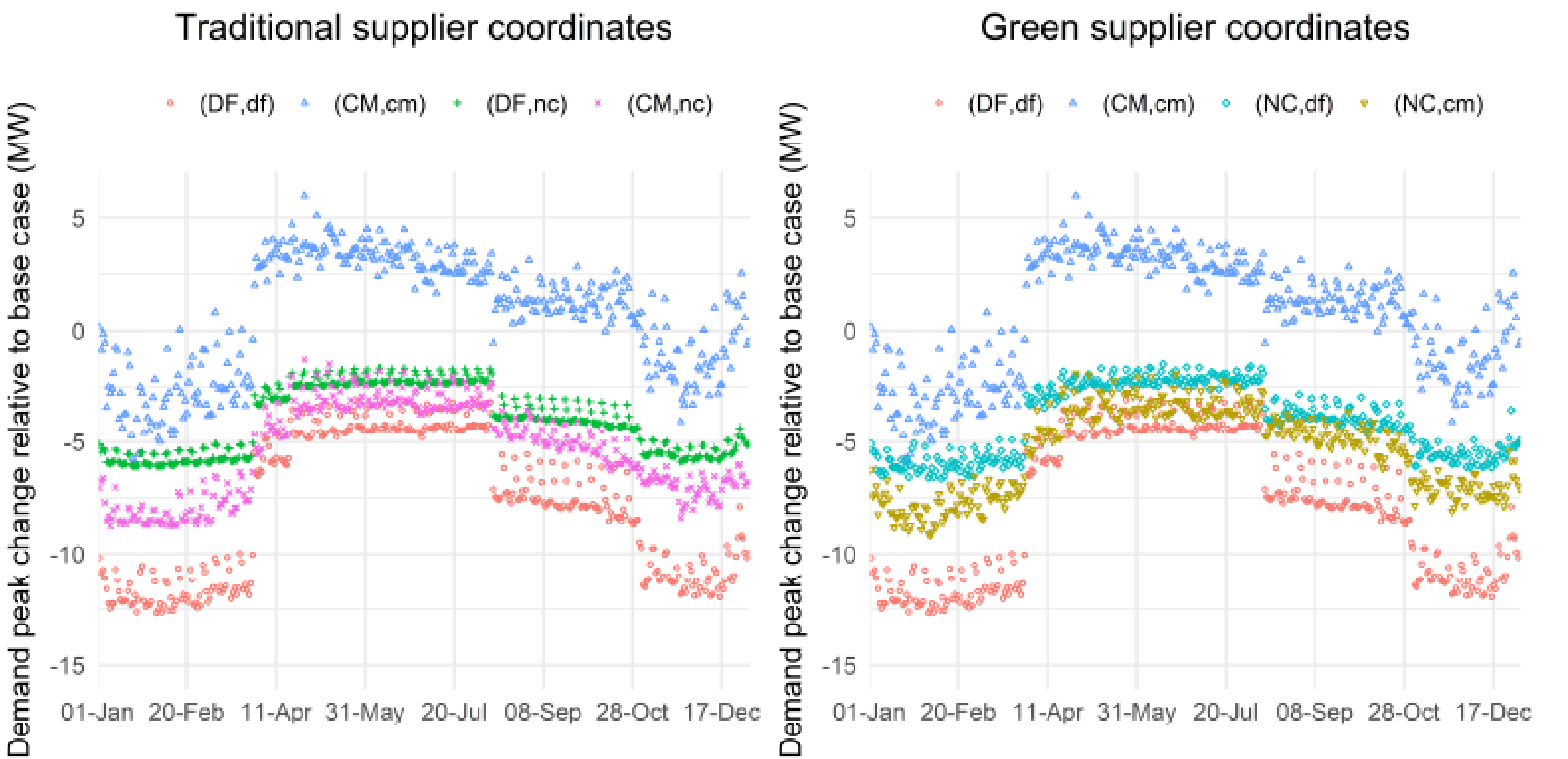
4. Results

Fig. 5: Comparison of average annual retail prices achieved by suppliers.

- In all cases TS performed better or as well compared to base case compared to GS regardless of DSM strategy
- TS was most competitive when it cost minmised, i.e. (CM,cm)

4. Results

Fig. 7: Change in daily demand peaks relative to base case (NC,nc) by experimental scenario.



- Cost minimising strategy led to an increase in system demand peaks

5. Conclusions

- DSM used as a tool to compete can lead to higher demand peaks → **Should DSM activities between suppliers and consumers be disclosed?**
- The competitiveness of green supplier depends on consumer responsiveness
- Relevant regulatory framework for DSM is likely to be required in the future

5. Further work

Development

1. Introduce other consumer resources: heat pumps, thermal stores, electric vehicles, resistance heating.

2. Allow consumers to switch suppliers.

3. Introduce more advanced learning strategy to suppliers.

Reasoning

1. More realistic representation of flexibility.

2. Explore scenarios when the number of consumers is uneven.

3. Eliminate some parameter dependence.

Thank you

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Questions?

Additional slides

Assumptions

1. Storage is equally distributed between different types of consumers
2. Consumers of the same type are identical => aggregated
3. Ancillary services are excluded from the market
4. Electricity costs are modelled at short run marginal costs (SRMC)
5. Power trading is not modelled
6. The merit order is constructed based on SRMC of generation technology
7. The model is deterministic
8. The transportation sector is not modelled
9. Pump storage is operated last after consumer coordination
10. Suppliers have an equal number of consumers
11. GS does not sell electricity in the market

Storage constraints

C1: Maximum and minimum power constraints

$$0 \leq f_i^{a+} \leq f_{max}^a, 0 \leq f_i^{a-} \leq f_{min}^a, \qquad \forall\, i \in [1, H],$$

C2: Storage efficiency constraint

$$\sum_{i \in H} f_i^{a-} = \eta^a \sum_{i \in H} f_i^{a+},$$

C3: Energy that can be stored or used at a time slot

$$f_i^{a-} \leq \sum_{j=1}^{i-1} \left(\eta^a f_j^{a+} - f_j^{a-}\right), \qquad \forall\, i \in [1, H],$$

$$f_i^{a+} \leq e^a - \left(\sum_{j=1}^{i-1} \eta^a f_j^{a+} - f_j^{a-}\right), \qquad \forall\, \mathrm{i} \in [1, \mathrm{H}],$$

C4: no-reselling allowed

$$f_i^{a-} \leq d_i^a, \qquad \forall i \in [1, H].$$

Where,

d_i^a - total electricity demand of consumer a in daily period i [MW],

i, j - period of daily simulation,

H - total number of periods in a daily simulation

Storage constraints

For an electric vehicle we have an additional constraint:

C5: the time constraints for charging

$$\sum_{i=t_1}^{t_2} f_i^a = (SOC_2 - SOC_1) \cdot e^a.$$

Where,

$f_i^a = \eta^a f_i^{a+} - f_i^{a-}$- is the net charge of the battery in time period i [MWh]

t_1, t_2 – start and finish time of charging (specified by the consumer),

SOC_1, SOC_2 – initial and final states of charge of the battery (as specified by consumer).

Centralised coordination algorithm

Input: The aggregator known the base load, b_i and the number N of consumers. Each consumer $a \in \{1, \ldots, N\}$ knows its flexible demand and constraints. The utility sets K – the number of iterations.
Output: Flexible load schedule $\boldsymbol{f^a} = f_i^{a+} - f_i^{a-}$ $\forall\, i \in [1, H]$

1) Set k=0 and initialise the flexible load schedule as

$$f_i^{\ a}(0) = 0, \qquad \forall\, i \in [1, H], a \in A$$

2) The aggregator calculates the average aggregate load per consumer

$$g_i(k) = \frac{\sum_{i=1}^{N} d_i^a}{N} \qquad i \in [1, H],$$

Where,

$$d_i^a = b_i^a + f_i^{\ a}(k) - f_i^{\ a}(k)$$

and sends the signal $g_i(k)$ to all consumers.

3) Each consumer solves the following optimisation problem for $\boldsymbol{f^{a+}}, \boldsymbol{f^{a-}}$:

$$\min \textstyle\sum_{i=1}^{H} g_i(k) d_i^a + \frac{1}{2}(d_i^a - d_i^a)^2 \quad \text{S.T.C.}$$

Set $f_i^{a+}(k) = f_i^{a+}$ and $f_i^{a+}(k) = f_i^{a+}$

and report new demand profile to utility, d_i^a

4) Set k=k+1, If k<K go to step 2).

Source: http://users.cms.caltech.edu/~adamw/papers/eEnergy2013.pdf

TS learning

Fig. 6: Electricity dispatch capacity and offer set by traditional supplier in experimental scenario (CM,cm).